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NATURE OF TYPE I SUPERNOVAE

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16. Abstract Supernovae were divided into two classes in 1940. A comparison of Supernovae I and II shows similarities between them. Supernovae I are unique in that they explode into elliptical galaxies. An analysis of composition is made and a discussion of various hypotheses on the evolution of galaxies and the nature of the Supernovae is presented.

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NATURE OF TYPE I SUPERNOVAE

I. S. Shklovskiy

Back in 1940, the division of Supernovae into two types [1] proposed by Minkovskiy had undergone testing with time. Attempts to introduce new types of Supernovae had appeared unfounded (see for example [2,3]). Now it is already clear that in the Universe actually there are two different types of exploding stars. These explosions are accompanied by a basic restructuring of the stars. Empirically we know that the final products of the explosion are: a) neutron stars (in certain cases, possibly black holes), b) envelopes which form from the outer layers of pre-supernovae expanding at a rate of 10-20 thousand km/s, c) the release of a tremendous quantity of energy in the form: 1) optical radiation -- up to approximately 10^{50} erg, 2) kinetic energy of the envelope approximately 10^{51} erg, 3) a flare proposed but not yet detected (lasting approximately 1 second) of neutrino radiation approximately 10^{53} erg. The primary source of all of the types of energy listed above is gravitational energy generated during collapse of the interior parts of the pre-supernovae. The order of magnitude of this energy is $W_G \sim \dfrac{GM^2}{R}$ when $R \sim 10^6$ cm and $M \sim 10^{33}$ g $\sim 10^{53}$ erg. This means that more than 99% of the total energy **released** during a gravitational collapse is transformed into a neutrino flare which although it is UV, slips away from observation. The coefficient of transformation of gravitation energy to optical and kinetic is very small -- less than 1%. If one takes into account that neutron stars are formed as a rule during flares of Supernovae of both types (but that there are serious bases of an empirical character), then in both cases W_G must be a single magnitude. /4 This circumstance that the quantity and power of radiation energy and also kinetic energy of the envelope has one order of magnitude for flares of Supernovae of both types (although the physical nature of exploding stars must be very different) one can find out that the coefficient defined above of transformation is a value more or less

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* Numbers in the margin indicate pagination in the foreign text.

constant for all exploding stars. Apparently, only in this way can we, for example, understand the astounding fact that the absolute values of Supernovae I and II, at the maximum, are fairly close (according to Tamman [4], $Mpg(SN\ I) = -19\overset{m}{.}1 \pm 0.25$; $Mpg(SN\ II) = -17\overset{m}{.}2 \pm 0.25$).

What conclusions of the most general character can one make about the nature of pre-supernovae of both types? It is easier and more reliable to make such conclusions about Supernovae II (SN II). It has been known for some time (see our monograph [5]), that Supernovae of this type never explode into elliptical galaxies but only into spiral, where one observes a strong concentration in the branches (Van den Bergh, Maza [6]). The average of Z, the coordinate in Supernovae of this type is much smaller than in Supernovae of type I (SN I). Also we should note that the average Z, the coordinate of residual flares, is very small and increases with distance from the center of the appropriate galaxy which is characteristic for distribution of clouds of interstellar gas (see Henning and Wendker [7]). Because a significant part of the residue of flares must belong to the SN II, this circumstance must be considered as an independent argument in the use of "ultraflat" spatial distribution of SN II in spiral galaxies. There are a number of other circumstances, for example, the dependence of frequency of flares SN II on the color of the galaxy [4].

On the basis of the characteristics listed above of spatial distribution of SN II, we pointed out back in 1960 that the corresponding pre-supernovae must be young massive stars which, are found in the main to belong to the spectral class O and earlier B (Shklovskiy [8]). Later on, this conclusion was reached by other authors and at the present time has a good basis (see the interesting review by Tinsley [9]). Empirically, from an analysis of the frequency of flares of SN II, the statistics of massive stars and time scales for their evolution show that practically all stars with a mass exceeding 7-8 $M_{\odot}$, must at the end of their evolution explode like the SN II (Shklovskiy [8], Tinsley [9]). The question of the causes of explosion of massive stars has many times been considered by theoreticians (see the numerous works of Nadyezhin, Imshennik et al., for example [10,11]).

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Although, in our opinion this problem still does not have a satisfactory solution, the methods of solving it are already clear and many processes which accompany an explosion of massive stars are fairly completely understood (for example, the peculiarities of neutrino radiation, a heat wave, which to a significant degree determines the curves of brilliance and color, etc.). The most important -- astronomers have now completely proved this, is which stars explode like SN II; it is still far from clear why they explode.

A completely different hypothesis was complicated by the historical discoveries of early SN I. To begin with, during three decades, their spectra consisting of a large quantity of very broad bands were not identified. Only in 1967 did Yu. P. Pskovskiy [12], relying on the pioneer work of D. McLaughlin [13] give a correct interpretation of these spectra. As is known, McLaughlin first directed attention at the "valleys" between the broad quasi-emission bands in the SN I spectra, interpreting them as absorption lines, strongly expanded due /6 to the tremendous dispersion of radiant velocities in the envelope. Meanwhile, before this, all attempts at identification involve interpretation of these bands as broad radiation lines. Yu. P. Pskovskiy, starting from the fruitful idea of expected similarity in conditions of formation of lines in photospheres of light blue supergiants (where the effect of absolute value is strongly expressed) and envelopes of SN I, considered it correct to identify certain absorbed details in the spectrum of the latter. The peculiarity of the SN I spectrum is the tremendous value of velocity of expansion of the envelope resulting in a significant shift in wavelength of central sections of strongly expanded absorption lines. For this reason, the spectral components of SN I are blended to the greatest degree. Final confirmation of the truth of identification by Pskovskiy is observation in the SN I spectrum, which exploded in 1972 into NGC 5253, of the infrared CaII triplet about $\lambda 8600$, predicted by Pskovskiy on the basis of identification of the H and K lines in spectra of a large number of SN I.

A more detailed comparison of the SN I and SN II spectra shows a great similarity between them. The main spectral details (H + K,

Na I, CaII λ8600) belong to a number of very noticeable ones in the spectra of both types of Supernovae. Often, the spectral details have a characteristic profile which was observed in the stars of the P type by Lebed. The most important difference, however, is the very large intensity of Balmer lines of hydrogen in the SN II spectra and their almost complete absence in the SN I spectra. However, one should note that in the SN 1972 spectrum, exploded into NGC 5253, a comparatively weak line was observed which American observers identified with Hα [14]. However, such identification is, at least disputable, and E. R. Mustel', for example, generally considers that in the SN I spectra there are no traces of Balmer lines [15]. In any case, /7 one can confirm that the chemical composition of the SN I envelope is very peculiar and, primarily, is characterized by a relatively low content of hydrogen whereas it is impossible to exclude the idea that there is almost no hydrogen. A large number of details in the SN I spectra are exactly explained by the fact that their envelopes consist primarily of heavy elements. In opposition to this, the SN II envelopes have a more or less normal chemical composition, in particular, a relative abundance of hydrogen and heavy elements close to the solar (see Branch and Patconnett [16]).

It is necessary to note that this difference in the SN I and SN II spectra must not be explained by the difference in physical conditions in the envelopes. The temperatures of the photosphere, after maximum brilliance and their dependence on time (determined by the colored curves) for both types of Supernovae are very similar [17]. They are also close to the values of electron density (see [18] and [19]). Therefore, the differences in spectra (primarily, the practical absence of Balmer lines in the SN I spectra) reflect the actual differences in chemical composition.

One more qualitative difference between chemical composition of the SN I and SN II envelopes make it possible to draw an important conclusion. Namely: in opposition to pre-SN II, stars which explode as SN I, at the moment of explosion, must evolve strongly and lose the external envelope which is rich in hydrogen.

The most important of the facts observed applicable to the SN I is the circumstance which has been known for some time that they are unique types of Supernovae which explode in elliptical galaxies. Moreover, on the basis of a statistical analysis by Van der Bergh and Maza [6] SN I have a tendency to explode on the periphery of the E galaxy. This conclusion was drawn taking into consideration corrections for observation selection due to the large central surface of brightness of E galaxies which decreases the probability of observing flares in their central regions. This spatial distribution means that stars explode a halo belonging to the oldest population of fairly rich heavy elements of objects whose age is approximately 10^{10} years. In spiral galaxies, SN I form a flat system corresponding to a fairly old population of the disk [4].

A comparatively high content of heavy elements in the population of the E galaxy to which the pre-SN I belong, comes from the proximity of indices of light of the periphery of these galaxies and certain spherical clusters with comparatively high "metallic properties." However, one should keep in mind that even in such clusters, the content of heavy elements, as a rule, is several times smaller than on the Sun. For example, in the hundreds of clusters with known relative content of heavy elements, presented in B. V. Kukarkin's catalog [20], only three have metallic properties slightly exceeding the Sun's. From this one can conclude that the primary content of heavy elements in pre-SN I in E galaxies must, most probably, be several times smaller than on the Sun. If this is so, then for the time of evolution of approximately 10^{10} years (the age of this population) from the main sequence, stars converge with a mass much smaller than $1.2 \, M_\odot$. Most probably, this mass is close to $1 \, M_\odot$. Thus, we must consider pre- SN I strongly evolved stars in which the external layers take on a radical transformation of chemical composition and where, in particular, hydrogen is practically absent. Such stars can be white dwarfs, nuclei of planetary nebulae , and also under certain conditions (see below), components of fairly restricted binary systems.

Coming to this conclusion based on fairly reliable observational facts which have been established, we immediately encounter a serious

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difficulty. So that the white dwarf, like any star, can col-
lapse into a neutron star (and in this conversion, the substance of
the phenomenon is the flare of a Supernova), necessary so that its
mass will exceed the Chandrasekhar limit $M_c = 1.4 M_\odot$ (assuming a car-
bon-oxygen chemical composition. Being on the main sequence, this
star must have had a still larger mass (approximately $1.6 M_\odot$), because
in the process of formation of a white dwarf from a red giant, this
external envelope either is separated, having formed planetary nebulae
or was scattered due to stellar wind. How does this agree with the
results obtained above that at the present time in the E galaxies that in the
population belonging to SN I, they come from with the main sequences
only of stars $M \sim I M_\odot$?

There are two conclusions in this controversy. In the first
place, one can propose that SN I are components of binary systems in
which, at a comparatively late stage of evolution, overflowing of the
mass occurs. Such overflowing can increase the mass of the pre-super-
nova to a value exceedingly critical, approximately $1.4 M_\odot$. Secondly,
one can consider that pre-SN I are recently evolved stars with mass
$> 1.4 M_\odot$, that is, white dwarfs.

First let us consider the second possibility: in E galaxies,
very old "relict" white dwarfs which formed a long time ago ($\sim 10^{10}$
years ago) explode. For billions of years they exist as stable objects
after which they catastrophically lose their stability and collapse /10
which one observes as the SN I phenomena. Expressing this graph-
ically, such white dwarfs are like "bombs" with a time fuse effect.
We can point out only one fundamental cause for the loss of stability
by the white dwarf, after having passed through a more or less pro-
longed period of quiet evolution. This is the presence in a white
dwarf of masses exceeding the Chandrasekhar maximum. Ostriker, par-
ticularly, pointed out this possibility [21] which he proposed existed
in white dwarfs involving their rapid turn to instability powerfully
resulting in their collapse. However, a new kind of serious develop-
ment of this idea has been obtained. However, one can point out two
actual mechanisms of loss of stability of white dwarfs which formed

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from a mass which easily exceeded the Chandrasekhar maximum, occurring a long time after their birth. The first mechanism which as far as we know no one has discussed, results in the consideration of the evolution of strongly magnetized rapidly rotating white dwarfs. Such dwarfs must be generators of fairly powerful magnetic-dipole radiation and for this reason, similar to a radio pulsar gradually decrease the angular velocity of its axial rotation. It is obvious that for a rotating white dwarf, the maximum mass must be higher than the Chandrasekhar value M_c, obtained for a case when axial rotation is absent.

Quantitatively, this question was studied by Annand [22] and Blinnikov [23]. According to [22], the critical mass of a rotating white dwarf M_c $(\Omega = 0) + \Delta M$

$$\frac{\Delta M}{M_c (\Omega = 0)} = 0.03 \frac{\Omega^2}{\Omega_o^2} = \frac{0.6}{P^2}, \qquad (1)$$

where $\Omega_o \sim 2$ s^{-1} -- is angular frequency at which rotational stability of a white dwarf is lost. Due to the magnetic-dipole radiation, <u>/11</u> slowing down of rotation of the white dwarf with an excess mass undoubtedly must occur at the moment when this mass becomes more critical; after this gravitational collapse must occur. Let us now evaluate the time τ necessary for this delay. The power of the magnetic-dipole radiation is defined by the expression

$$L_m = \frac{2}{3C^3} H_o^2 R^6 \sin^2\theta, \qquad (2)$$

where θ -- is the angle between the axis of rotation and the magnetic axis. Then

$$\tau = \frac{I}{2} \frac{\Omega}{L_m} \sim \frac{10^8}{\Omega^2} \qquad \text{years}, \qquad (3)$$

where $I \sim 10^{50}$ cm^{2}g -- is the moment of inertia of a white dwarf. From (2) it follows that for this so that τ will be $\sim 10^{10}$ years $H_o \sim 3 \cdot 10^7$ gs (this corresponds to the value of the field on the surface of the "magnetic white dwarfs") one must, so that Ω 0.1s^{-1}, which corresponds to the period of rotation $P \sim 60$ s; from this, according to

(1) $\dfrac{\Delta M}{M_S(\Omega=0)} \approx 10^{-4}$.

Thus, in principle this mechanism of collapse is completely possible. In other words, it is realized in nature to a certain degree, that is, the results of observation confirm it. In turn, the discussion goes on to the magnetism of white dwarfs and their axial rotation. At the present time (see Angel [24]), ten white dwarfs are known with powerful magnetic fields (from approximately $3 \cdot 10^6$ to approximately 10^8 Gs). In two cases, periodic variations of the degree of circular polarization were detected, undoubtedly due to axial rotation. For the Feige object -- seven periods $P = 130$ min, at the same time that for G 195-19, $P = 1.33$. In the other eight cases, axial rotation of white dwarfs was not detected -- it is too slow.

The fact that in white dwarfs one does not observe magnetic fields weaker than $5 \cdot 10^6$ Gs, cannot be explained by the low sensit- ivity of the receiving equipment. The latter is completely capable for comparatively bright white dwarfs of recording a field of $H \sim 10^4$ Gs. One can conclude in white dwarfs H is either very large ($> 5 \cdot 10^6$ Gs), or comparatively small ($H \le 10^4$ Gs). One can estimate that the portion of "magnetized" white dwarfs is approximately 1% of their full number. Let us direct attention to the slowness of axial rotation of white dwarfs. Comparatively rapidly rotating objects are the exception. For example, in the recent work by Greenstein et al., [25], from the 14 white dwarfs studied, only a few have an equatorial velocity of rotation of 60-70 km/s (which corresponds to $P \sim 10^m$) and most are less than 30-40 km/s. There is a simultaneous combination of three properties in the white dwarfs observed: a) an excess mass $\Delta M/M_c \sim 10^{-4}$, b) a strong magnetic field $H > 10^7$ and c) a rapid axial rotation $\Omega > 1 s^{-1}$, has an extremely low probability. If these three characteristics are independent, then the probability of such a combination is very low (for example, for the E galaxies this probability is $\sim 10^{-7}$, that is, at least several hundred times smaller than the necessary value -- see below).

Besides the "magnetic," there is another mechanism long before in time stabilizing the white dwarf with excess mass, rotating it as a "time bomb." This mechanism can be called "thermal." A number of theoreticians have pointed out that the slow contraction of a white dwarf whose mass slightly exceeds the Chandrasekhar limit at the temperature of the interior $T = 0$, leads it in the final analysis to a critical state with a subsequent collapse into a neutron star (Hoyle and Fowler [26], Arnett [27], Bisnovatyy-Kogan and Seidov [28]). The cause of the slow contraction of white dwarfs can be either the β-process (Finzi-Wolf [29]) and the simple cooling of white dwarfs (Bisno- /13 vatyy-Kogan and Seidov [28]).

The excess (in relation to $T = 0$) maximum mass of the white dwarf is determined by the expression [28]

$$\frac{\Delta M}{M_c} = 2 \cdot 10^{-4} \cdot \frac{24}{A} \cdot \frac{\mu_e}{2} \cdot T_7 ,$$ (4)

where A -- is the average atomic weight of the matter of the white dwarf, $\mu_e \sim 2$ -- is the number of nucleons per one electron, T_7 -- is the temperature of the interior of the white dwarf, expressed in units of $10^7 K$. Without considering the various type of fine effects (see below), the cooling time of the white dwarf with mass $> M_c$ ($T = 0$) up to the critical state results in its collapse,

$$\tau_1 = 2 \cdot 10^8 \cdot T_7^{-2.5} \cdot \frac{24}{A} \cdot \frac{\mu_e}{2} \quad \text{year.}$$ (5)

In a case of SN I flares in E galaxies, our problem is to determine ΔM, as soon as τ_1 is known $\sim 10^{10}$ years. However, with such long-term periods of evolution, the necessity arises for taking into consideration certain fine effects. Primarily, one must consider the effect of crystallization of matter and also convection of the interior of the white dwarf. These processes are accompanied by absorption of thermal energy which results in more rapid cooling than according to formula (5). According to the numerical calculations of Lamb and Van Horn [30], for this reason the time τ_1 decreases by 2-3 times. However, one should note that calculations made by Shaviv and Kovetz [31] result in a significantly slower cooling than in [30]. All these authors, however, do not take into consideration that in the cooling

process contraction of the white dwarf with a mass very close to (and exceeding) M_c (T = 0), in its central region begins 2-stage reactions of β-captures (see Bisnovatyy-Kogan, Seidov [32]). Because of the presence of this additional source of thermal energy, the white giant with mass $M > M_c$ for a fairly long time will be close to the critical /14 state so that it, in the final analysis, collapses.

Everything that has been said applies to the interval of mass M_c, $M_c + \Delta M$, where $\Delta M/M_c \sim 2 \cdot 10^{-4}$ which, as we will see below, can correspond to a case of the E galaxies. A rough estimate indicates that for the interval of mass of interest to us, the additional generation of heat due to nonequilibrium β-processes compensates for cooling due to crystallization and convection. Therefore, in the first approximation, for large time intervals and fairly small values of ΔM it is possible to use formula (5). From the tables presented in [30], taking the directions contained in [32] into consideration, one sees that for 10^{10} years, the white dwarfs cool to $T_7 = 0.2$. From this, according to (4), in "relict" white dwarfs, which exploded as SN I in E galaxies

$$\Delta M/M_c \sim 3 \cdot 10^{-5}. \tag{6}$$

According to Tamman [33], the ("specific") frequency of flares of SN I in E galaxies calculted per unit of mass[1] is

$$f = 4 \cdot 10^{-3} \cdot \left\{ (10^{10} M_\odot) \cdot (100 \text{ лет}) \right\}^{-1}. \tag{7}$$

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[1] The low specific frequency of flares of SN I in E galaxies can be directely confirmed on an example of a giant spheroid stellar system NGC 4486, whose mass is $\sim 10^{13}$ $M_\odot$. For the entire time of telescopic observations, only one Supernova exploded in 1919 [5]. Because the mass M87 was several tens of times larger than the mass of the Galaxy, we directly find that the specific frequency of flares of SN I is hundreds of times lower than in the Galaxy. It is curious that in the M31, the Supernova explodes approximately once in a hundred years (the last time in 1885). In this case we note that in the M31, the rate of star formation also was a magnitude smaller than in our Galaxy. This is similar to the fact that the M31 in type is much closer to Sa than Sb.

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If the number of all white dwarfs in these galaxies amounts to $\sim 10\%$
of the number of all stars, then for 10^{10} $M_\odot$ masses they must be at
least $\sim 10^9$. Using the function of mass of newly formed white dwarfs
[34] (although very unreliably), one can assume that the number of
white dwarfs with $\Delta M/M_\odot \sim 3 \cdot 10^{-5}$ must be $\sim 10^4$. Meanwhile, the number
of flares of SN I for 10^{10} years, calculated at 10^{10} $M_\odot$, must be at
least approximately $3 \cdot 10^5$, that is, approximately 30 times larger than
the number of expected white dwarfs with $\Delta M/M_\odot \sim 3 \cdot 10^{-5}$. Finally, this
estimate is very rough but nevertheless it indicates that the mechanism
considered cannot provide the expected frequency of SN I in the E Gal-
axies. In the best case, only approximately 1% of the flares can be
explained by this mechanism.

Now let us consider the evolution of pre-supernovae in binary stel-
lar systems found in in the E galaxies. An important characteristic
of this evolution is the exchange of mass between components of the
system. This can lead to the occurrence of comparatively massive
stars in E galaxies where the process of star formation has recently
stopped. Moreover, in principle, one can theorize that during evolu-
tion in a binary system, a specific situation can arise which results
in explosion and which in a unique evolving star cannot occur. In
other words,   it is logical to assume that the Supernova phenomenon
(like an ordinary nova) can occur only in multiple stellar systems.

Historically, the first of such possible specific mechanisms of
explosion of stars was pointed out by Shatzman [35]. After him, a
number of authors pointed out similar ideas appropriate to the E gal-
axies for which recently the difficulty   indicated above with the
masses of exploding stars was found out (see Truran and Cameron [36],
Hartwick [37], Whelan and Iben [38] and also Gursky [39]). The es-
sence of this idea consists of the fact that "active" (that is explod-
ing) components of the system are a recently evolutionized white dwarf
which is formed with a mass somewhat smaller than a Chandrasekhar
limit M_c, whereas the initially smaller massive component succeeded
in evolving fairly adequately. This component can either be subgiant
(at the early stage of its evolution) or an object of a small mass

($M < 0.5\ M_\odot$), similar to the nondeveloped component of new and nova-like stars. In the process of overflow of mass from a nondeveloped component to a white dwarf, the mass of the latter can exceed M_c; after this, a gravitational collapse must follow. Opposite this mechanism of explosion is the well known objection: after overflow on to a white dwarf of a rich hydrogen substance, it follows most rapidly that one should expect an ordinary flare of a **Nova,** then in the process of this flare a small excess mass will be ejected. The objection to this however is not decisive because, in principle, one can propose that in certain rare cases of mass ejected during a flare, on the average, it is smaller than the mass which overflowed on to the white dwarf between the flares. This question has not yet been theoretically developed properly.

The Shatzman hypothesis, primarily, must prove the known facts applying to flares of Supernova in multiple stellar systems. In one considers that the Shatzman idea can give a universal explanation of all SN I flares, then it must be applied to the galactic objects. Here we will immediately run into an important fact. The point is that the presupernova of 1054 could not have been a component of a binary system. On the other hand, if this system after explosion of SN did not disintegrate[2], a strong effect of orbital motion of the NP 0532 pulsar would have been observed; this did not occur.

Another actual objection to the universality of the Shatzman mechanism is an analysis of the situation in the binary PSR 1913 radio pulsar. In this system, as is known, the radio **emission** component is a neutron star and the other component is either a white dwarf or a neutron star. Because the radio **emission** . component (neutron star) must have formed later than the second component (if this is a white dwarf[3], then it can be fed by accretion: then the second component is a very compact star practically without stellar wind.

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[2] We note that because during symmetrical explosion of SN I, a comparatively small part of the matter of a more massive component is lost, the pair cannot be broken apart. If this explosion is asymmetrical, then due to large gravitational energy of the bond, breaking the close pair also is not to be expected.

For the problem under consideration, an analysis of galactic binary systems is of great importance; one of the binary components is a neutron star -- the undoubted residue of a Supernova flare. Such systems are not so different from X-ray pulsars. The known properties of these systems, as we see them, exclude the possibility of formation of a "neutron" component of the Shatsman mechanism. Let us consider for determinancy, a binary system of the X-3-Centaurus in which the "optical" component is a light blue supergiant with powerful stellar wind "feeding" the X-ray source -- neutron star. Because the duration of the phase of a light blue supergiant in massive stars must be only approximately $(2-3) \cdot 10^5$ years, if the neutron star in this system occurred using the Shatsman mechanism, then its age would have been approximately 10^5 years. However, due to the short orbit time, it could not be transformed from elliptical (after the explosion) to al- /18 most circular. Moreover, the full quantity of gas which underwent accretion during the phase of the supergiant, preceding the explosion, must be approximately 10^{-4} $M_\odot$. Consequently, the white giant must have had a mass of a magnitude smaller than the Chandrasekhar limit. But such objects must be very small (see above), several magnitudes smaller than the number of X-ray sources of this type. What has been indicated also applies to the X-ray source of the Her X-1 type, where the primary masses of a component were comparably small.

However, a class of galactic X-ray sources exists in which the neutron stars are components of restricted binary systems, possibly, formed by the Shatsman mechanism. We are talking about objects of the Sco X-1 type, and X-ray sources in spherical clusters. In these objects there is an optical luminosity of a non-confluent component a thousand times smaller than the X-ray luminosity of the source. Consequently, this component, a dwarf star with small mass, is similar to a non-confluent component of cataclysmic restricted binary systems. Consequently, there are serious reasons to propose that the X-ray sources of this type resulted from restricted binary systems using the

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[3] In the opposite case, the neutron star would be wrapped in a fairly dense envelope with mass of several tens of $M_\odot$. But such an object is not a neutron star!

Shatzman mechanism. However, the frequency of flares of SN I caused by the appearance of such sources is very small. The time of evolution of cataclysmic systems caused by loss of mass of a non-confluent component, is at least $\sim 10^8$ years. Because in the galaxy, one counts $\sim 10^2$ X-ray sources of this type, one finds directly that the specific frequency of SN I flares caused by the Shatzman mechanism $f_m \sim 10^{-5}/$ 10^{10} $M_\odot$ 100 years, which is ~ 1000 times smaller than that observed in the E galaxies, because the number of cataclysmic systems in the Galaxy is $\sim 10^5-10^6$, and the time for their evolution is $\sim 10^8$ years, so that it is only in one of several thousand such systems that a flare /19 of SN I can occur.

We can still conclude that in restricted binary systems, made up of massive stars, due to the overflow of external envelopes of evolutionary components enriched with hydrogen, only SN I can flare up. Consequently, only single massive stars must flare up as the SN II (or components of fairly broad pairs).[4]

Thus, purely empirically we can conclude that in binary systems -- X-ray sources -- the evolved component explodes due to certain "internal causes" after which, a significant part of its mass overflows as a secondary component. Also it is possible that the secondary component explodes after this as the substance overflowed from the primary and that it successfully evolved fairly well. Apparently, an example of such evolution could be the binary PSR 1913 radio pulsar. We can evaluate the specific frequency of SN I flares caused by this process. Of the approximately 200 radio pulsars, only one has entered into the composition of a restricted binary system. From this one can conclude that only approximately 0.5% of the reformed pulsars enter into the composition of restricted binary systems. Because one pulsar in the Galaxy is formed approximately once in ten years, it is

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[4] Is this astonishing fact explained in that incorrect galaxies of the Magellan type, where so many massive young stars have been observed only in SN I up till now, and in that the percentage of single massive stars is noticeably smaller than in the late spirals? And is this not why the absolute values of luminosity of all SN I at a maximer here are $\sim 2^m$ larger than in the spirals (see [4])?

immediately obvious that in restricted binary systems, the specific frequency of flares of SN I is $f \sim 5 \cdot 10^{-3}/10^{10} M_\odot \cdot 100$ years, which also corresponds to the frequency of SN I in E galaxies. It is obvious that such a frequency of flares can also occur during explosion of a primarily more massive component in a restricted binary system. We have already said above that in separate (rare) cases evolution is possible according to the Shatsman system. The facts however tell us that in the overwhelming majority of cases, explosions of SN I are caused by "internal" processes in the evolved star. Figure 1 diagram-**matically** shows three possible methods ("channels") of evolution in binary systems, making it possible to produce an SN I flare-up. The first corresponds to the Shatsman mechanism, the second to the formation of X-ray pulsars, and the third to formation of radio pulsars in binary systems.

Turning to the problem of a flare-up of SN I in E galaxies, we see that most rapidly one must realise a "third path" (see Figure 1). Several billion years ago, having received an "added" mass from the first component (as a result of which its mass exceeded the Chandrase-khar limit), the second component of the system began its evolution so that in our epoch, it exploded like an SN I. With such a system of evolution, a certain interval of primary masses of primary components must exist which after a fairly prolonged evolution can, with a certain probability, result in a flare-up of SN I. Assume $\tau \sim 10^{10}$ -- is the time which passes after completion of an epoch of star formation in E galaxies, τ_0 -- is the time of evolution of a second component after which, the mass from the first component overflowed on to it. Obviously, τ_0 is defined as the mass M_2' after overflow. It is clear that M_2' cannot be too large because then τ_0 would become small and $\tau - \tau_0$ would be too large for the mass M_1 to be adequately large. One can prove that M_1 must lie (approximately!) in the limit

$$1.15 < M_1 < 1.35,$$

while $\tau_0 < 5 \cdot 10^9$ years. Below, starting from this hypothesis, we will again evaluate the frequency of flare-ups of SN I in E galaxies.

Now let us go on to an analysis of flares of SN I in spiral galaxies. Finally, if **in elliptical galaxies, SN I flare up only in** binary systems, then in spirals this process must occur. The question however involves the fact of whether or not there is a basic part of pre-SN I in the spirals with components of binary systems. Or, in other words, is the fact that stars belong to a binary system a necessary condition for its explosion? Above the argument that the SN II must be massive single stars was presented. How will it be with the SN I? There is a considerable difference between S and E galaxies: in the latter, in this era there cannot be single stars with a mass larger than M_c which necessitates explaining the flares of SN I as a certain specific mechanism, namely, by their **duality.** This is not so in spiral galaxies where thanks to a permanently continuing process of star formation, there is a fairly adequate quantity compared to massive stars. Serious observation data exist which indicate that a significant if not the largest part of all SN I flare up among single stars or in comparatively "broad" systems. Let us pause to discuss this in more detail.

As is known, in the environs of SN 1604 (the Kepler star), there is gas with a normal chemical compositon [5]. Because the coordinate of this Supernova is approximately 1200 ps (a superfluous proof that it is an SN I), the density of the interstellar gas here must be very small, $\sim 10^{-2}$ cm^{-3}. The fairly bright cloud of gas observed around the SN 1604, undoubtedly, was ejected from the pre-supernova most rapidly at the stage of the red giant -- either by formation of a planetary **nebula** or due to stellar wind. This obviously could not be if the pre-supernova 1604 was a component of a comparatively rigid binary system. In this case, only overflow of the external envelope onto the second component could occur. We note a comparatively dense gas is observed around the SN 1006 (Z $\sim$ 600 ps). Obviously, the presence around the pre-SN **of gas with normal chemical composition** is a fairly widespread property of these objects. Most of all, this gas is planetary **nebula** separated from the corresponding pre-supernovae at the stage of red giants. The alternative possibility is stellar wind from red giants preceding the formation of planetary **nebula** -- at least it provides the presence of comparatively dense

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gas in the surroundings approximately one parsec from the star. This means that even with the power of corpuscular radiation approximately $10^{-6} - 10^{-7}$ $M_{\odot}$/year, the velocity $v \sim 10^6$ cm/s, the density of the ambient atmosphere will be $\sim 10^{-25}$ g/cm at a distance of ~ 3 ps from the star -- a value too small. Then, it is assumed that the density of the ambient interstellar gas is insignificant -- a condition which is fulfilled at a fairly large distance from the galactic plane.

Thus, we come to the concept that in a number of cases pre-super-novae of type I can be objects similar to the nuclei of planetary cloudiness. This concept, in particular, explains the absence of hydrogen in the SN I envelopes. Because yearly in the Galaxy 1 - 3 new planetary clouds form and SN flare up approximately once in several decades, one can conclude that for each 30 - 100 nuclei of planetary **nebulae** evolved into white dwarfs, there is one which has exploded as an SN I.

Using this conclusion one can also talk about the closeness of characteristics observed of SN I in S and E galaxies (for certain differences, see below). But in the latter pre-SN I, there must be objects which evolved by confluence of objects in their central regions which make them similar nuclei of planetary **nebulae.**

It would be more natural to consider the cause of explosions an anomalously large value of the mass of the nucleus exceeding the Chandrasekhar limit M_c, from which it follows that in the main sequence of mass of pre-SN I, it was approximately 1.5 - 1.6 $M_{\odot}$. The first time (approximately 10^5 years) that the nucleus evolves into a white dwarf, it will be stable.[5] However, when in the process of such evolution, the nucleus in the structure is fairly closely related to a white dwarf, collapse sets in. We have already noted that an excess mass can be fairly significant, for example, approximately 0.01-0.1 $M_{\odot}$. Attention is given to the fact that of several

[5] For instance, keep in mind that certain nuclei of planetary nebulae in which the spectrum is detected as having WR characteristics, lose mass due to stellar wind. Most often, this loss is insignificant.

hundred planetary **nebulae** only in the units considered, does the nucleus enter into the composition of the binary system. From all of the galactic populations, only the radio pulsars are the residue of flare-ups of Supernovae and have this property. This also can indicate the genetic bond of nuclei of planetary nebulae and pre-SN I. We have already noted that spatial distribution of both populations is fairly similar.

From the fact that the overwhelming majority of planetary nebulae is not a component of a binary system, one can draw one more important conclusion. In recent times, **the view was propagated** that the basic part (up to 98%) of stars with mass 1-2 $M_\odot$ are components /24 of multiple systems (see Abt [41]). Abt, for example, found that from stars brighter than 5^m, whose spectral classes are A4 - F 2, 23 are magnetic (A_m) whereas they are all components of comparatively restricted binary systems ($\bar{P} \sim 4^d$), and from the other "normal" A-F stars studied, 17 are spectral-binaries whereas if one takes into account possible unobserved low mass components, the percentage of multiple systems can increase significantly [42].

We note that A-F stars are of particular interest to us because some of them, in the final analysis, must evolve into SN I. However, because a significant part (in our estimate greater than 30%) of red giants in the last stages of their evolution form planetary nebulae and at the same time their nuclei are isolated objects, one can conclude that **more** than 30% of stars of the main sequence with the mass indicated above must be single.

It is possible to draw another conclusion that the stars A_m which are never single, as a rule, cannot have evolved into SN I. At the same time, we note that in distinction from ordinary A - F stars, these stars rotate slowly [42]. Only the "normal" A - F stars in a case of their collapse at later stages of evolution can form rapidly rotating neutron stars which, as we will see later on, has the principal significance for the entire problem.

It is impossible, however, to confirm always the SN I form from certain nuclei of planetary nebulae. We have already seen above that

SN I can flare up in restricted binary systems. In this case, it is difficult to show the formation of planetary nebulae in the process of evolution of one of the components.

On the other hand, with a fairly large distance between the components, the latter must evolve in the same way that they would if they were isolated. From the fact that the rate of expansion of planetary nebulae is usually 20-40 km/s, with the natural assumption that these velocities are close to the parabolic velocity of the corresponding star-giants, it follows that the radii of the latter must be approximately $3 \cdot 10^{13}$ cm. Therefore, the minimum period in this system at which evolution of components can be considered independent (and where planetary nebulae can form) must be approximately a few years. We note, however, that with such an independent evolution, effective exchange of mass does not yet occur. Therefore, in elliptical galaxies, where SN I flare up primarily in binary systems (see above), the periods of the latter must not exceed a few years. Consequently, the formation of planetary nebulae and specific evolution of stars in a binary system, is accompanied by exchange of mass -- concepts which are mutually exclusive.

It would seem that one should expect a fairly significant number of nuclei of planetary nebulae -- components of broad pairs with $P > 1000^d$. One can propose that in these rare cases where the nucleus of planetary nebulae has a spectrum of the A - F class, this situation is observed more than once. It is also necessary to keep in mind that during formation of planetary nebulae (which is generally speaking, an asymmetrical cloud), the pair can be separated due to the appearance of an additional impulse of "recoil" in the nucleus. It is possible, consequently, to expect a flare-up of SN I in broad pairs. Most often, however, in this case the separation of the pair will occur.

Now let us evaluate the frequency of flares of SN I in restricted binary systems according to the data of X-rays astronomy. For determinancy, we will consider X-ray sources of the Her X-I type, whose

optical component has a mass somewhat exceeding the mass of the Sun.
Their full number in the Galaxy is approximately 100, and the charac-
teristic lifetime of sources of this type, determined according to
century acceleration of their axial rotation $t = P_T/P_T \sim 10^5$ years.
It follows from this that the frequency of flares of Supernovae
(usually, type I) in compact binary systems (here the pair is not
separated) approximately once in a thousand years is approximately 30
times smaller than the frequency of flares of all SN I in the Galaxy
[4]. Even lower (by several times) **is the frequency of flares of SN I
in compact binary systems with a massive opitcal component of the Cen S-3
type, if one takes into account that the duration of the stage of**
the   light blue supergiant (and accompanying this stage powerful
stellar wind) is approximately 10^5 years.

One can assume that in elliptical galaxies, a portion of the
binary systems, in relation to the full number of stars, is approxi-
mately the same as in the spiral. The basis for this conclusion is
the fact that in spherical clusters (whose stellar composition must
be close to the E galaxy), for the last one hundred years one has
observed, with full verification, two Nova flares (in the NGC 6093 in
1960 and NGC 6402 in 1933). On the other hand, in the entire galactic
disk, annually approximately 100 Novae flare up. Taking into account
that the total mass of all spherical clusters is approximately 10^{-3}, of
the mass of the galactic disk **and that 1-2 Novae in the clusters could have
passed through, we find that the "specific" frequency of Nova flares
which are components of compact binary systems in spherical clusters
and the disk, must be practically the same. We note that in spherical
clusters, also stars of the U Geminorum type were observed.**

Then how do we understand the fact that specific frequency of
flares of SN I in the E galaxies is approximately several tens of
times smaller than in the spirals? Here, the percentage of the binary
media of stars with mass 1.5-2 $M_\odot$ and a period smaller than a few
years (in other words the substances from M_1 to M_2 will not overflow),
is at least, 20-30%. Apparently, this involves the fact that in
binary systems, the SN I flares occur, at least, with a probability

smaller by a magnitude than single stars which would indicate the
example given above of X-ray pulsars. The cause of this, possibly,
is too large a value of overflow mass from the evolving component.
Therefore, the mass of the latter rarely exceeds the Chandrasekhar
limit M_c, without which an explosion of a star is impossible.

Now let us evaluate the specific frequency of flares f in the
E galaxies. Let us assume that approximately 30% of the stars in
elliptical galaxies are binary, and of these 1/15 are newly formed
stars which have a mass within limits 1.15-1.35 $M_\odot$ (see the well
known work by Salpeter [43]). The probability that in the process
of evolution in a binary system the Supernova explodes and one does
not obtain, as usual, a white dwarf $\quad$ is $\quad \sim \quad$ 1/300 (that is,
approximately ten times smaller than for single evolving stars --
see above). Then, for 10^{10} stars in an elliptical galaxy for 10^{10}
years, the SN I explodes as

$$10^{10} \cdot 1/15 \cdot 0.3 \cdot 3 \cdot 10^{-3} = 6 \cdot 10^5,$$

and for 100 years $\sim 5 \cdot 10^{-3} (10^{10} M_\odot \cdot 100 \text{ years})^{-1}$, which is close to the
value observed (see [33]). Thus, the mechanism of "binary stars"
can quantitatively explain the frequency of flares observed in the
E galaxies.

Whereas in the S galaxies the SN I is primarily (by 90-95%) single
stars or components of fairly broad pairs (which is one and the same
thing) and in E galaxies approximately 99%, the flares occur in fairly
close ($P < 1000^d$) binary systems (approximately 1% can be white dwarfs
with low excess mass) makes one expect certain differences in the
basic characteristics of SN I which have exploded in galaxies of both
types. Such differences must be in the form of a curve of brightness /28
and in dispersion of the absolute values at the maximum. The latter
must be noticeably larger in the S galaxies because in the E galaxies,
the mass of pre-SN I cannot exceed a certain limit whereas in the S
galaxies, the pre-SN I can have large masses. A reflection of this
circumstance can also be the curious differences in the curves of
brightness of the SN I, which have flared in galaxies of different
types, observed recently by Yu. P. Pskovskiy [44]. Although the

curves of brightness are fairly similar, certain characteristic differences are apparent among them. The characteristic parameter of the curves of brightness is the rate of decrease of brightness $\frac{dm}{dt}$ after the maximum, expressed in stellar values per day. Table 1 contains the results of a statistical analysis made in [44].

TABLE 1

$\frac{dm}{dt}$ (m/day)	E + S0	S	Im
0.06	--	5	--
0.07	--	I	--
0.08	--	5	--
0.09	7	I	--
0.I0	4	7	.
0.II	--	3	.
0.I2	2	I	I
0.I3	--	--	--
0.I4	I	2	2

It is apparent from Table 1 that as one could expect, the photometric properties of SN I in the E galaxies is noticeably more uniform than in the spiral galaxies. However we note that if the SN I /29 flares in the E galaxies were caused by the Shatsman mechanism, then their photometric characteristics would have been identical and this was not so. Attention should be given to the fact that in the E galaxies, the three "lowest" photometric classes of curves of brightness were completely absent. This characteristic of Table 1 is hardly explained by the inadequacy of statistics. It is possible that this is due to the "limitation on top" indicated above of the massive pre-SN I in the E galaxies. The "lowest" photometric classes give very "broad" (about maximum) curves of brightness. We will address this question below.

Right now we will go on to the important problem of interpretation of curves of brightness of SN I. As a result of a number of theoretical studies of different models of exploding stars [10,11] it became clear that with instantaneous release of energy it was possible to obtain theoretical curves of brightness somewhat similar to those observed; it was necessary to assume that the radius of the envelope of the pre-Supernova must be very large, $> 10^{14}$ cm. Moreover, the analysis presented above leads one to conclude that pre-SN I must be very compact objects close to a white dwarf.

Beginning in 1976, D. K. Nadyezhin and V. P. Utrobin, in several works, first calculated models of flares of Supernova stars with slow generation of energy (that is, "pumping" [45,46,47]). Calculation showed that the characteristics of the Supernova close to the maximum hardly depend at all on the assumed radius of the pre-Supernova, if it is only smaller than the radius of the photosphere of SN close to the maximum, that is, less than 1000 $R_{\odot}$. In other words, these calculations are true for very compact pre-SN. The characteristics of the Supernovae depend on the mass of the envelope M_e ejected during the explosion and on the rate of "pumping" of energy L_e. For an explanation of the curves of brightness observed one needs pumping of energy /30 at first at a level of $10^{44} - 10^{45}$ erg/s and after a certain time (determined according to the bend in the curve of the light index) -- at a level of $10^{42} - 10^{43}$ erg/s. Moreover, for agreement between the calculated and the observed curves of brightness, one must hypothesize that after the maximum of brightness in the envelope, there is an increase in the irregularity of ionization.

A comparison of models which are calculated for different values of mass of the ejected shell, makes it possible to show some interesting principles:

1. As the mass of the envelope M_e increases, luminosity decreases at the maximum.

2) Both effective temperature at the maximum decreases and

also the radius of the photosphere R and the velocity of the envelope V.

3)   The width of the curve of brightness increases, that is, its "photometric class" becomes "earlier".

In [47], an important relationship was obtained from which the principles listed above follow:

$$\left(\frac{M_e}{M_\odot}\right)^{0,4}\left(\frac{L_e}{10^{44}\,erg/s}\right)^{0,8}\left(\frac{V}{10^8\,cm/s}\right)^2\left(\frac{\varkappa}{1\,cm^2/g}\right)^{0,4}=44,3, \quad (8)$$

where $\varkappa$ -- is the coefficient of opacity.

Using these results for the data in Table 1, we see that in the S galaxies in certain SN I, the mass of the envelope is larger than in the E galaxies which have exploded. Due to this, let us note the fact that the average luminosity of SN I in the S galaxies is approximately 1^m lower than the E galaxies. At first glance, the fact that this agrees well with the conclusion on the large average masses of the envelope in spiral galaxies seems strange. One only has to make a fairly natural hypothesis that the mass of the envelope depends on the mass of the pre-Supernova in the main sequence.

From an analysis of the characteristics of the Supernovae type
I in [47], masses of their envelopes $M_e \sim (0.2 - 0.6)M_\odot$ and the kinetic energies $E \sim (2-5)\cdot 10^{50}$ erg is in good agreement with estimates obtained from an analysis of the residue of galactic Supernovae.

The conclusion that during a flare of SN I, comparatively slow (that is, lasting 10^6-10^8)pumping of energy takes place, is of particular importance for the entire problem. The question arises: what is the nature of this pumping? Various authors have proposed two different mechanisms. Historically, the first was a "radioactive" mechanism proposed back in 1956 by Fowler, Baade, Christy and Hoyle (the California 254 hypothesis) [48]. Later on it underwent some

modifications. For example, Anders considered Fe-59 as the radio-active element [49] but Leventhal and McCall used the small chain of radioactive β decomposition Ni-56 → Co-56 → Fe-56 [50]. Unfortunately, the authors of these hypotheses, while very clever (for example, [50]), concentrate their attention exclusively on a single (although important) aspect of the problem -- an explanation of the quasiexponential curves of brightness of SN I, ignoring the other aspects. For example, in the case of realization of the California 254 hypothesis, the cosmic abundance of other heavy nuclei would have been hundreds of times larger than that observed.

The "slow" pumping which can be called "rotation-magnetic" or "pulsar" is a much more promising mechanism. Pioneer studies in this field were completed by G. S. Bisnovatyy-Kogan [51] and after him by Ostriker [52,53]. In this case, the energy of pumping is derived from the kinetic energy of a rapidly rotating neutron star which is transmitted externally by a magnetic field acting like a "drive belt." More specifically -- one is looking at pressure of a magnetic-dipole radiation (caused by rotation only of the magnetic neutron star formed) and accelerated by this radiation of charged particles (the so-called /32 "pulsar wind") to the outer shell of the collapsed star. The shock wave occurring here emerging on the surface of the star provides an optical luminosity of a Supernova. The variety of the "pulsar" mechanism is a mechanism of pumping proposed by us of a rigid X-ray radiation of a young pulsar [54]. Calculations indicate that this mechanism represents curves of brightness of SN I fairly well. However, one should note that the "pulsar" mechanism of pumping energy in the SN I shell must undergo further development.

The fact that kinetic energy of the shell and also energy radiated during an flare of SN I, is the conversion kinetic energy of rotation of a neutron star and has an exceptionally large value for all Supernovae problems. For example, it is necessary to assume that all pulsars are residues of flares of Supernovae, and during their formation must have very brief periods of rotation: $10^{-2}-10^{-3}$ s. Moreover, in the opposite case it would be impossible to observe the

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phenomenon of the flare of a Supernova itself. This imposes certain limitations to the nature of the pre-Supernovae and the explosion mechanism. For example, in a compact binary system ($P < 10^6$ s), where rotation of the components must by synchronous, an explosion cannot occur caused by the Shatsman mechanism because in the neutron star formed, the period of rotation would be too long and the kinetic energy too small. If, as we consider, the direct forerunners of SN I are objects close to the nuclei of planetary nebulae, then at the beginning of its evolution (that is, assuming a comparatively short time after separation of planetary nebulae from the red giant), their radius must be $\sim 10^{10}$ cm, and the period of rotation approximately a few days. This period of rotation is common for stars whose spectral <u>/33</u> class was earlier than the F 2. Therefore, one must conclude that in pre-SN I, where they are found in the main sequence, the central regions are rotated with the same angular velocity as the exterior shells and at the red giant stage, the angular velocity of the central regions remains unchanged. It is natural that such rotation accumulates well known limitations for possible concepts on evolution of the center of such stars. The fact that most white dwarfs are slowly rotating objects means that the evolution of stars most often leads to the formation in them of comparatively slowly rotating nuclei. Finally, one must assume that on the surface of compact pre-Supernovae (massive nuclei of planetary nebulae) there must be a magnetic field $H \sim 10^4$ oersted -- a value which we do not consider too large.

In the conclusion of this article, we will pause to discuss one very interesting but particular problem. It is well known that the Crab nebulae, in comparison with other residues of flares of Supernovae is a peculiar object to the highest degree. We have pointed out [55] that all of the unusual properties of this nebula are due to the exceptionally low rate of expansion of its fibers which must not be considered as slowing down the envelope in the interstellar medium (on the other hand, the system of fibers due to pressure of the magnetic field and relativistic particles are accelerated). The modern rate of expansion of the system of fibers in all is only approximately 1500 km/s, that is, approximately 10 times smaller than

the usual rate of expansion of SN I shells. In accordance with this, the kinetic energy of the shell is approximately 10^{49} erg, that is, almost 100 times smaller than in the "normal" shells of the Supernovae, both of the first and of the second types.

In [47], a model of a Supernova flare 1054 was constructed based on the mechanism of slow pumping of energy. According to [47], the characteristics of this Supernova was a very small power of pumping which all of the time was at a level of $\sim 10^{42}$ erg/s; moreover, in the normal SN I, the first is $\sim 40^{d}$ power of pumping $\sim 10^{44}$ erg/s and then is maintained at a level of $\sim 10^{42}$ erg/s. Of course, formally one can explain the peculiarity of the Crab nebulae adjusting according to the dependence of power of pumping on time. However, extending the hypothesis in [47], without solving the problem, one encounters difficulties in another direction. It is still unexplained why the character of pumping was as is proposed in [47]. An objection is also raised to the too low luminosity of the Supernova 1054 at its maximum which was assumed, correspondingly, as $M = -16^{m}.5$ (in [4], the value $M = 18^{m}.2$ is introduced).

Without rejecting the final attempt to explain the anomalous state of the Crab nebulae, similarly to [47], right now we propose a hypothesis **which** is the logical result of the concept **of** the nature SN I flares developed in this article.

The difficulties involved in interpretation of the Crab nebula, to a significant degree, are removed if one assumes that the "star-visitor" 1054 was usually SN I, being at the time the nucleus of a fairly compact planetary nebula. Then, the interpretation of the Crab nebula fiber is past condensation of the planetary nebula, which "interacted" with the shell of the Supernova, having expanded at a velocity of approximately 15,000 km/s. Such an interaction must have the following results: a) a change in the morphology of condensation of the planetary nebula, that is, the formation of a thin-fiber structure, b) enrichment of these condensations by heavy elements, c) a sharp increase in the rate of condensation to the

value observed approximately 1500 km/s. We note that such a velocity is observed in the SN 1604 fiber (Kepler) and is not a part of the Supernova shell.

A significant, if not the main, part of the shell with energies ~ 10^{50} erg must break between the condensations of the planetary nebula in the ambient fairly rarefied ($n_H < 0.1$ cm^{-3}) interstellar medium and slow down in it.

If the shell of the Supernova 1054 "was stuck" in the planetary nebula, it would heat the gas formed to a temperature (ion) on the order of hundreds of KeV. Because this is not observed, one must assume that almost all of the energy of the explosion E was radiant. With this hypothesis, we again encountered insurmountable difficulties (for example, a flow of X-ray radiation from the Crab nebula must be tens of times in excess of that observed).

Thus, having made the supposition that the fibers of Crab nebula observed were formed not from the shell of a Supernova, but from a cloud of gas found around the blasted star (most often -- a planetary nebula); we must consider that the "true" dimensions of the residue of the flare of the SN 1054 must be considerably larger than the Crab nebula. Using the well known formula coming from the self-modeling solution of Seidov problem for a strong explosion [4]:

$$R = 10^{15}\left(\frac{E}{E_0 r_0}\right)^{1/5} \cdot t^{2/5}, \qquad (9)$$

where $E_0 = 7.5 \cdot 10^{50}$ erg, t = $3 \cdot 10^{10}$ s, $n_0 = 0.1$ cm^{-3}, we find that the radius of the residue of SN 1054 is approximately 4 ps for which a distance of 2000 ps corresponds in the II'. Consequently, if the expressions developed above correspond to actuality, around the Crab nebula there must be a fairly weak extended (~ 20') source of comparatively rigid X-ray radiation (energy of the quanta on the order of a few hundreds of keV). Moreover, there must be such angular dimensions with a weak radio source from the envelope structure. The

flow of X-ray radiation from this source ~ 10^{11} erg/cm^2 s, that is, a comparatively small value. It was interesting to attempt to detect this X-ray source during the subsequent series of eclipses of the Moon by the Crab nebula.

As to the proposed comparatively prolonged radio source surrounding the Crab nebula, its expected surface brightness must be fairly low. Consequently, this source is not easy to isolate from the surrounding galactic background. Because of this, one must remember that the prolonged (approximately 40') radio source with low brightness PKS 1465-41, found at the location of the Supernova 1006, was detected by Milne only in 1971 [56], although the conditions for its observation (in particular, the high galactic latitude, approximately 15°) is considerably more favorable in comparison with the Crab nebula.

Attempts to discover the comparatively extended (approximately 20') radio source in the environs of the Crab nebula must be considered as very important. There is not only interest in attempting to discover by optical methods very weak thin fibers not unlike those which recently were discovered by Van den Bergh in the field of the extended radio source PKS 1459-41 SN 1006) [57]. We note that on the Palomar atlas in the environs of the Crab nebula nothing similar is visible (for example on similar photographs of the SN 1006).

A decisive test for judging the hypothesis presented above as to the origin of the Crab nebula is a final clarification of the question of chemical composition of the gas in the fibers. If it is "normal" (that is, the hydrogen itself is fairly abundant), then this will be a strong argument in favor of this hypothesis; if it is peculiar (for example, an abundance of helium over an abundance of hydrogen), then this hypothesis is "closed." Although in literature there are indications of a similarly high content of helium in the fibers (Davidson [58]), the entire question cannot be considered as solved because the interpretation of appropriate observations raises a number of objections.

There was interest in obtaining, in the spectrum of the Crab nebula, the L_α lines of absorption from gaseous fibers, with strong (~ 6 Å) violet shift.

I (E galaxy, X-sources)

II (X-sources)

III (E galaxies)

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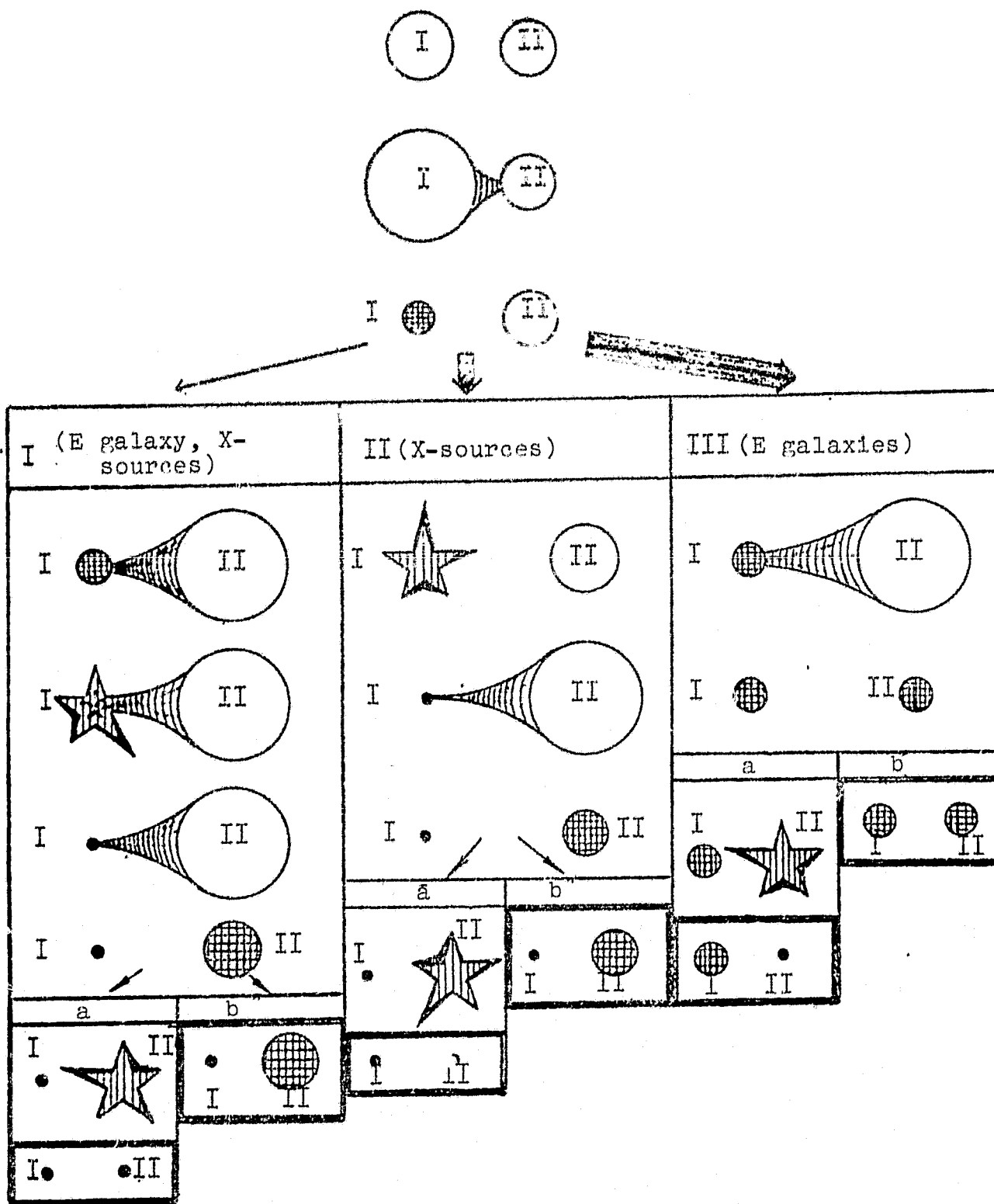
A diagram of different methods of evolution of stars in compact binary systems powerful enough to produce a SN I flare.

The overwhelming majority ($\sim 99.9\%$) of systems evolved according to the III, b "channel."

$\sim 10^{-3}$ -- according to channels II and III, a. The smallest part ($\sim 10^{-6}$) -- according to channel I.

Conventional Symbols:

○ -- A non·degenerate star

◯▷ -- An evolved non-**degenerate star with effluent**
   mass

⊕ -- Degenerate star

☆ -- SN I flare

● -- A neutron star

▭ -- Final state of evolution

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